3.7.4.1 Auxiliary Transformers

The new transformers will operate reliably until 2035 provided improved standards of maintenance are maintained throughout the period. It is recommended that assessments should be performed at minimum 5 yearly intervals until 2025 and with an increased frequency of 3 yearly intervals after 2025. The increased frequency after 2025 is in recognition of the fact that some ageing will have occurred and it is preferable that any negative trends are detected and corrected early. Early detection and timeous intervention ensures high levels of reliability are maintained and reduces costs.

The original transformers are not in a satisfactory state. However, most of these transformers, if refurbished soon, can operate to 2025. This is important because the cost of refurbishment is approximately half the cost of a new transformer. However some of the auxiliary transformers are beyond economical refurbishment. Therefore if operation to 2035 is required, it is important to check the thermal ageing status of the transformers prior to refurbishment. Units with advanced thermal ageing must be replaced.

It is clear that the original transformers will not operate reliably unless there is an intervention in the very short term. It is recommended that an in situ refurbishment be performed. It is anticipated that possibly 20% of units may be found to be beyond refurbishment and will need to be replaced. This intervention will give reliable operation until 2025 with a few failures between 2025 and 2035.

Note that due to the current state of the transformers it is possible that isolated failures may occur prior to, during or immediately after the intervention before settling down. The possibility of failures occurring in the last years can be minimized by applying more strict targets for the furan/DP tests (see implementation), which it is expected will result in some aged transformers being replaced rather than refurbished. The costing allows for up to 20% replacement.

To prevent further deterioration of the auxiliary transformers, the Eskom mandatory Standard 240-56358993 "Standard for the maintenance of power transformers" should be complied with now and in the future. The inspection and corrective actions stipulated by this mandatory standard would prevent the moisture ingress that has inflicted so much damage on Hendrina's auxiliary transformers. Noncompliance with this standard has significantly contributed to the need to refurbish all of and to replace some of Hendrina's auxiliary transformers.

3.7.4.2 Measurements and Metering

The metering systems are critical as they measure the energy produced by the station, consumed internally and sent to transmission. Presently none of the systems on Hendrina power station comply with Eskom standards in respect of metering method, independency and accuracy class as defined in the new Eskom EMDAS requirements (see section 2.10.4.2). There are also additional requirements for metering internal loads.

All of the system components, including VT's and CT's and associated transducers, must therefore be replaced by 2015. At the same time additional VT's and CT's must be installed in order to meet the Main and Check system requirements. New metering must be installed for the Excitation Transformers, Station Supplies, Loop Supplies and Diesel Generators.

According to the new standard these meters will then not need replacement for a further 12 years, so this intervention will ensure life extension to 2025. However for life extension to 2035 it will be necessary to replace the meters again by 2027.

3.7.4.3 LV Motors

Original unit-plant related LV motors within the station should be replaced immediately as a high priority. This is because these machines are already uneconomical to operate and cannot be considered acceptable for operation until 2025. They are over 40 years old (as against a design life of 20 years) and repeated rewinding has degraded their electrical performance (efficiency, life between rewinds etc.) and their mechanical life (bearing journals and shaft journals have become damaged on an increasing number of machines.)

Original common-plant related LV motors operating in more favourable environments should be replaced by no later than 2025. Many failures have already occurred and these machines will become increasingly unreliable and may need to be replaced earlier.

Newer unit-plant related LV motors within the station should be replaced around 2025 to maintain reliability and economic performance.

It is recommended that unnecessary safety factors (of motor kW rating) for replacement machines are done away with in order to enhance efficiency, in line with modern practice. It is also recommended that any replacement machines should be high efficiency units. Numerous studies show that the payback period is typically less than a year.

The adoption of a predictive maintenance strategy - as opposed to the current reactive maintenance plan – is recommended to achieve the highest operational reliability and lowest cost life extension to 2035.

It is recommended that Hendrina re-assess their LV motor repair philosophy as it is not economical to rewind small motors. Anglo American has a guideline that motors below 30 kW should be replaced and not rewound; but this policy is not yet finalized. SASOL do not rewind machines below 45 kW; Sasol revise this cut-off according to the copper price and the cut-off has been as high as 110 kW. The power cut off for replacement is even higher if the failed machine is an old, "standard" energy efficiency machine. These arguments apply for the first rewind; for repeat rewinds the economic case is even stronger when one factors in that each rewind typically reduces the motor efficiency by 1% to 3%. Any LV machine that requires mechanical work other than replacement of bearings (e.g. rebuilding shafts or work on bearing housings) should be scrapped.

Retrofitting of high efficiency motors requires appropriate engineering as the operating current of high efficiency motors is lower (so protection settings need to be reviewed) and the starting current is some 10% higher (so contactor ratings need to be reviewed). There are numerous papers on the repair or replacement of LV motors and the comparison of high efficiency motors with earlier machines. For example, van Niekerk, J & Cristolini, E, "High or premium Efficiency motors", Beltcon 16, 3-4 August 2013.

3.7.4.4 MV Motors

The current population of MV motors is in a very poor condition and the majority of motors are past their economic and reliable life. The machines are around 40 years old, that is double their design life and have operated in harsh conditions with overloads, misalignment, and so forth. Therefore a replacement program will be necessary in order to support a plant life extension to 2035 whilst maintaining operational reliability and managing costs.

If scheduled outages allow, then motors should be replaced according to highest risk of failure that is first ID fan motors, EFP motors, PA fan motors, ash pump motors, FD fan motors and finally CW pump motors.

It is essential to procure replacement motors to an appropriate specification. Factors to be considered include motor shaft load (including possible load increases such as is expected of some fans), environmental conditions (including ambient operating temperature, dust loading and so forth) operating conditions, modern condition monitoring and so forth.

On-line predictive maintenance techniques should be adopted, especially with regard to the electrical aspects of the motors, in order to improve reliability and reduce the cost of ownership.

Until the on-line condition monitoring is introduced, considerable benefit would also be found in conducting more thorough off-line assessments during GO's by identifying and correcting incipient faults that presently go undetected.

Specifications for replacement motors should require an improved surge suppressor (higher temperature rating [at least 55°C], higher harmonic rating [at least 10% THD V, and resistance to rupture) to the ZORCs to be mounted in the motor stator terminal box. (Several ZORC MV motor surge suppressors, mounted in the PILCSWA / XLPE cable link box, have exploded. This is a personnel safety violation – the ZORCs are filled with oil – and an equipment safety violation. Further, surge suppressors are ineffective unless mounted right at the motor terminals, or, less effectively, at the switchgear. However, the mill motors are specified for 60 °C which is above the capability of available surge suppressors. Therefore the mill motors should have surge suppressors installed at the switchgear rather than at the motors.

It is important that all existing MV motors which are to be controlled by new switchgear should be protected by functioning surge suppressors. This is because earlier machines, which were operated by oil breakers, typically have inadequate inter turn insulation to withstand the voltage transients imposed by modern SF6 or vacuum switchgear.

It is recommended that 5% of MV machines minimum one of each type of motor be included in the replacement order and held at Hendrina as strategic spare.

3.7.4.5 MV Cables

Holes below the switchgear should be made off in compliance with Eskom Standard 240-56227443 "Requirements for Control and Power Cables for Power stations Standard", clause 3.7 Sealing of holes in floors and walls and fire barriers. Blocking holes off with rags constitutes a fire hazard.

No intervention is required for operation to 2035 in the case of the approximately 10% of cable that is XLPE.

Operation to 2035 with the existing PILCSWA cables is not feasible as the rate of failure would become intolerable from about 2020 to 2035. If it is intended to extend the life of plant to 2035 and maintain reliability then complete replacement of all the original PILCSWA cables is the recommended option. In this case the cost is justifiable because of the minimum 10 year extended service life. It is also significant that when replacing PILSWA cables, recommended practice is to also replace all adjacent cables. This is because aged PILCSWA cables may continue to operate satisfactorily for years if undisturbed, but any disturbance significantly increases the probability of their failure.

In the case of the mill motors where life extension to 2035 is required and which have mixed cables, it is also recommended that the complete cable length be replaced so as to both eliminate the risk of PILCSWA cable failure and the risk of explosions associated with the "ZORC" suppressors.

Workmanship should be of such a standard that moisture ingress should not cause buried MV cable joints to fail. It is strongly recommended that independent third party audits be performed on installation and jointing of all MV cable work, particularly that involving XLPE and PILCSWA.

In addition, condition assessment in service should be applied more rigorously.

Wherever possible, joints should be made above ground.

Rigorous control should be exercised to ensure that the correct type of joint is used, particularly when joining XLPE and this type of PILCSWA.

It is recommended that the Eskom Standard 240-56227443 "Requirements for Control and Power Cables for Power Stations Standard" be updated to include compliance with the newly released standard SANS 10198-13: "The selection, handling and installation of electric power cables of rating not exceeding 33kV. - Part 13: Testing, commissioning and fault location."

3.7.4.6 Busduct

As a matter of urgency it is recommended to investigate the cause of the high discharge levels on Unit 6. This should be at the first opportunity where access to the busduct insulators can be obtained at an outage of sufficient duration. NB: This is not a Life-ex issue but simply highlighting the presence of a potentially serious defect which could lead to a catastrophic failure before correction is possible in the Life-ex intervention.

Some bus-bar insulators are exhibiting defects that can lead to mechanical problems. These problems would pose a threat to the integrity of the bus-bar system and since this is a critical component of the generator/GSU system it should be addressed. The mechanism is slow, so it is not a matter requiring urgent attention. However the situation which has prevailed the past few years in which the busduct system is not maintained at all should not continue.

It is also recommended that the busduct condition be assessed, monitored and trended by conducting measurements of electrical discharge levels on all units annually. This can be done on-line with noninvasive and non-intrusive methods so it will not impact on production. An increase, especially if it is sudden, to very high levels should be investigated at a convenient outage.

All units should be subject to removal, inspection, test and refurbishment of all of the busduct insulators (and other parts of the busduct system; and not merely 63 as was done in this Life-ex study) whenever an outage permits access to the busduct for sufficient duration. Note that for this Life Ex not all insulators in units 3 & 9 were refurbished. Once so maintained it is not expected that further attention will be needed until 2035 other than the recommended annual on-line condition assessment.

It is noted that Eskom standard 240-56357295: "Specification for High Current Phase Isolated Generator Busbars used at Thermal Power Generating Plant" specifies that "phase isolated three-phase generator bus bars" shall be pressurized and that the standard "shall apply to all thermal generating plant of Eskom Holdings Limited". However, pressurization would be expensive when retrofitted to an old, existing system and to Eskom standards. Further, the standard is dated 2012 and is written for new stations (the second paragraph of clause 2.1.1 of the standard states "The specification is to be used as part of the enquiry package while purchasing new generator busbar and associated equipment.") Therefore the issues should be carefully considered.

Irrespective of whether the Busduct system is pressurized or not, the system needs to be cleaned and refurbished to achieve life to 2025, as discussed above. This will restore the Busbar system to a similar condition to "as new". The busduct system has rendered a 40 year trouble – free service to date. Therefore it is to be expected that the recommended intervention will allow operation of Hendrina till at least 2025, without the expense of retro-fitting pressurization. Therefore it is recommended that the busduct system does NOT need to be pressurized.

3.7.4.7 Switchgear Load Study

The Life-ex scope of work required only the obtaining of the PTM load flow study report.

According to this report it is recommended that the new internally arc compliant MV switchgear at Hendrina Power Station be rated for 25kA fault current.

3.7.4.8 Switchgear Protection

The Life-ex scope of work requires a replacement cost only, based on a PTM report. No recommendation is required, but from inspections conducted in the course of the Life-ex study it is clear that the switchgear protection is indeed urgently in need of replacement together with the switchgear itself (already scheduled). The cost for the replacement switchgear is provided.

Once it is replaced life extension to 2035 is anticipated.

3.7.4.9 Station Earthing / Earth Mat

The existing earthing systems and ground bed have to be tested and if necessary up-graded to be in compliance with the Eskom standard; 474-085. The regular inspection and testing of the earthing systems will provide service to 2035.

3.7.4.10 Generators

As only limited physical testing results are available, further tests have to be conducted in the next years to allow for more detailed interpretation of the results and for Eskom having the chance to react on occurring and increasing risks. Therefore the testing of the next stator during any General Overhaul should be taken into account. In case of a General Overhaul, Siemens should provide the entire test program to ensure a proper testing of all affected components. Besides this individual testing, Siemens should support Rotek's work during the next upcoming General Overhaul to ensure execution of the work according to the latest procedures of Siemens' guidelines. Additionally Siemens could provide an Advisor for the day-to-day operation and maintenance activities on site.

Based on the data available at this point in time, Siemens would like to present the following three Scenarios A, B, and C for the Generators at Hendrina power plant considering operation until 2035:

3.7.4.10.1 Scenario A - Keeping all current gas/water-cooled generators

Three rotor rewinds on the units that have not been rewound yet (unit 1, 6, 8) are included in Scenario A. The rotor rewinds Siemens would propose to be performed within the next two years address the increased risks of forced outages due to rotor faults.

Keeping all current gas/water-cooled generators may require a changed maintenance concept with reduced inspection intervals. Especially the units 8, 9 and 10 with paper insulated stator core laminations need a thorough testing which translates into a 5 year interval for pulling the rotor out of the stator and conducting the tests according to the following Siemens procedure: "Scope of Life Time Assessment Study for Generator Stators at Hendrina Power Plant, 2.14-0700-0002/1". Scenario A also includes inspection and overhauls of the remaining 7 units (1 – 7) with varnish insulated stator core laminations, which should be done at reduced time intervals to detect possible failures as early as possible.

Because of aging and non-compliance with today´s regulations, norms and standard, Scenario A also includes an exchange of the generator auxiliary systems on all of the 10 units: hydrogen gas system, waste gas system, stator water cooling system and seal oil system. Operation of the auxiliary system in current status until 2035 would constitute a significant risk for unplanned outages and personal injury.

Siemens would like to emphasize that operating the original generators until 2035 would translate to more than 500.000 equivalent operation hours. This is beyond the horizon of Siemens experience and considered as a very high risk of major failures and forced outages.

Note: Therefore Siemens does not recommend Scenario A for operation until 2035.

3.7.4.10.2 Scenario B – Considering 3 air cooled generators *plus three additional spare* replacement generators

Scenario B is based on implementing a generator replacement program which includes the replacement of the old generators of unit 8, 9 and 10 that feature paper insulated stator core laminations by three new designed and manufactured air-cooled Footprint generators. In order to address the risk of major failures on the remaining 7 units **in the extended operation until 2035** resulting in a long forced outage and corresponding loss of production, Siemens recommends to order three additional air-cooled Footprint generators which would serve as strategic spare parts. These spare generators would be equipped with a long term packaging and conservation suitable for storage on Hendrina site. Those spare generators would enable Eskom to secure shortest response time due to the fact that the time span for manufacturing and transportation would be saved in case of a generator failure. Within this scenario, the maintenance on the remaining 7 old generators can be reduced as potential spare generators are available.

The spare generator strategy could be accompanied by a reduced maintenance concept for the remaining original generators in Unit 1-7. When following this approach, the remaining old auxiliary systems of unit 1-7 would also be replaced by new systems because of the significant risk and danger as described above. By the time of implementing the air cooled Footprint spare generators, the auxiliary systems of the corresponding unit can then be decommissioned and removed.

The price indication for Scenario B is 96.960.000,- EUR = 1.405.920.000,- ZAR (1EUR = 14,5 ZAR) over a period of 20 years. As 3 generators are replaced by new equipment and 3 additional generators are available as spares, scenario B addresses the risk of failures for more than one unit in the extended operation until 2035.

3.7.4.10.3 Scenario C – Considering Replacement of all ten generators

Scenario C is based on implementing a generator replacement program which includes the replacement of all ten gas/water-cooled generators with new air cooled Footprint generators. The design and rating of the air cooled generators would also allow for enhanced performance due to possible boiler or turbine power uprates (please refer to section 3). In addition the maintenance costs for the air-cooled generators are significantly lower compared to the old gas/water cooled generators.

An advantage of replacing the gas/water-cooled generators with air cooled Footprint generators is that all the existing above mentioned generator auxiliary systems on all 10 units can be decommissioned and scrapped. This results in a significant reduction of the operation costs for the generators of the entire power plant.

The price indication for Scenario C is [redacted]- ZAR (1EUR = 14,5 ZAR) over a period of 20 years of which the majority of [redacted] ZAR are the investment into 10 new generators. As all generators are replaced by new equipment, scenario D provides a very high security of availability as well as lowest maintenance and operation costs.

3.7.4.11 Automatic Voltage Regulators (AVRs)

There is already a project initiated for replacement of the AVR's. The recommendation therefore is to maintain the availability of the UNITROL D AVR system by ensuring sufficient number of spares and diligently executing maintenance activities as in the past (PTM Witbank) for the next 2 – 3 years, until the planned replacement project commences. Since the existing UNITROL D may become obsolete before all units are outfitted with the replacements, availability of spares may become an issue. It is therefore recommended that as replacements are fitted, the removed Unitrol D AVR's are not disposed of but retained for spares until the replacement programme is completed.

It is expected that the execution of this AVR replacement will see the life of the station through to 2035, given the feasible life expectancy of an AVR installation.

3.7.4.12 Generator Protection

Prior to the commencement of the Life-ex study, Eskom had already established a contract for upgrading the Generator Protection Schemes within the next 3 years. With the correctly selected relays and maintenance according to the OEM and Eskom standards, there is high confidence that the upgraded generator protection will see the plant through to 2035.

3.7.5 Common Plant Area

3.7.5.1 Coal Handling

Findings to 2025 and 2035 are similar, *see chapter 2.7,* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - Ongoing concrete repairs on the coal staithes,

- Proposed additional:
  - Ongoing maintenance.

3.7.5.2 Boiler House

Findings to 2025 and 2035 are similar, *see chapter 2.7* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - Ongoing replacement of I-beams and leaks onto boiler house q-deck to prevent further corrosion under the suspended concrete floors.

- Proposed additional:
  - Ongoing maintenance.

3.7.5.3 Turbine Hall

Findings to 2025 and 2035 are similar, *see chapter 2.7* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - Extended repairs to q-deck and plant drain manholes.

- Proposed additional:
  - Ongoing maintenance to buildings.

3.7.5.4 Flue Gas Structure

Findings to 2025 and 2035 are similar, *see chapter 2.7.* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - Concrete base at baghouse unit 5 needs recast,

- Proposed additional:
  - Ongoing spalling repairs and cracks in concrete of baghouses and galleries.

3.7.5.5 Smoke Stacks

Findings to 2025 and 2035 are similar, *see chapter 2.7* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - Additional allowance made for treatments against high Sulphate levels, and
  - Severe deterioration of mortar between brick work in the upper levels (externally).

- Proposed additional:
  - Provision for extended routine maintenance.

3.7.5.6 Cooling Towers

Findings to 2025 and 2035 are similar, *see chapter 2.7* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:

  - Increase spall repairs from 50 to 100%.

- Proposed additional:
  - Provision for extended routine maintenance,
  - Additional replacement of IBR sheeting,
  - Additional Crane beam repairs.

3.7.5.7 Peripheral Structures

Findings to 2025 and 2035 are similar, *see chapter 2.7.* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - None.

- Proposed additional:
  - Provision for extended routine maintenance,
  - Additional replacement of IBR sheeting,

3.7.5.8 Sewerage and Waste Water

Findings to 2025 and 2035 are similar, *see chapter 2.7.* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - None.

- Proposed additional:
  - Provision for extended routine maintenance.

3.7.5.9 Ash Plant

Findings to 2025 and 2035 are similar, *see chapter 2.7.* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - The size of the new Ash Dam increases from 90 ha to 139 ha.

- Proposed additional:
  - Provision for extended routine maintenance.

3.7.5.10 Raw Water Reservoirs

Findings to 2025 and 2035 are similar, *see chapter 2.7.* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - None.

- Proposed additional:
  - None.

3.7.5.11 7 Year Dam

Findings to 2025 and 2035 are similar, *see chapter 2.7* In addition to interventions for 2025, the following additional interventions were identified to run to 2035:

- Critical and immediate:
  - None.

- Proposed additional:
  - None.

3.8 Cost and Program Projection

3.8.1 Boiler Plant Area

3.8.1.1 Boiler U1-U5

All cost stated below are for one unit:

The OEM only recommended the tower boiler upgrade for the capacity increase study, but it would be prudent to consider it for the option of running the plant up to 2035. The tower upgrade has the following advantages:

- Economiser and Primary Superheater will only have to be replaced once as and not twice as currently suggested. The erosion rate is drastically reduced which will result in much longer tube life.
- Air leakage will be reduced significantly which will result in more efficient boiler operations. This will also assist with the capacity of the ID fan, which Howden proposed to be replaced due to all the air leakages. This replacement won't be necessary if the is less air leakages.
- Due to the replacement of the furnace wall, fireside corrosion will not be a problem and the lengthy inspection won't be needed anymore.
- The modification will result in saving from outage cost as there will be very little work on the boiler for the next 15 years where after detail inspection will have to be conducted again. It would however be a good idea to do some inspection to monitor erosion and other failure method in order to plan preventive action for later in the boiler's life.

Table 315: Cost Summary for Units 1-5

	Life Extension to 2035	2035 Tower Upgrade
Improve Gas Flow Distribution	[redacted]	
Low NOx Burner Retrofit		
Modular Replacement of Tube Banks		
Tower Boiler Conversion		
Main Steam Piping Replacement		
Sootblower Piping Replacement		
Boiler and Main Steam Drains Replacement		
Feedwater Supports Replacement		
Auxiliary Steam Line Replacement		